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Strategic Roadmap Area 8
Exploration of the Dynamic Earth System

The Potential Impact of Space Weather on Climate and Biological Systems

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The Potential Impact of Space Weather on Climate and Biological Systems

It is generally accepted that the Earth's oceans, with their huge thermal capacity and intricate current circulation system, control our climate. Warm ocean currents keep the climate of Northern Europe more benign than it would be otherwise. Cool currents provide natural air conditioning for coastal California. Ocean currents have a circulation pattern that has a cycle time of thousands of years and hence cannot explain variations in climate on time scales significantly shorter than that circulation period.

There are many examples in the Earth's biosphere of variations in climate and weather patterns that are apparently correlated with solar activity. For example:

- The carbon-14-isotope content in tree rings and dust content in ice cores follow the 11-year solar cycle.
- The dramatically cold winters experienced by northern Europe during the 17th and early 19th centuries occurred during times of low sunspot numbers (i.e. low levels of solar activity).
- The current global warming corresponds to the most active period in the Sun's recorded history, when sunspot numbers are large.

While these correlations are highly suggestive of an intimate link between space weather and climate, possibly even weather, no physical mechanism or combinations of mechanisms has been shown to link the varying conditions in geospace with effects in the Earth's atmosphere. Further other effects such as human influences, volcanic eruptions, and sea-surface temperature changes can cause large and sudden changes in climate and weather systems that would probably overwhelm any measurable solar influences.

The problem lies in the fact that the total solar irradiance varies only by about 0.1% over a solar cycle. This variation is based on measurements taken only in the last 20 years and could be much larger over longer periods. The differential energy absorbed by the Earth as a result of such a small change in the "solar constant" should not be sufficient to power dramatic changes in climate. The long time constant of the ocean currents would act to smooth out these variations to an average value. The lack of a proven transport mechanism is a final problem in linking these phenomena.

Several possible mechanisms have been suggested but none have been established as viable. For example:

- Cosmic ray flux modulation by solar activity could change cloud and precipitation patterns by acting as a source of condensation nuclei.
- High-energy electrons injected into the Earth's magnetosphere from coronal mass ejections being precipitated into the upper atmosphere cause heating in the polar regions changing wind patterns.
- Induced currents from geomagnetic storms may have an effect not only on technological systems like power grids but also in biological systems themselves.
- Absorption of high-energy radiation (X-rays, γ -rays, and EUV) from intense solar flares and large active regions causes changes in the scale height, chemistry, and thermal balance of the atmosphere at lower latitudes.

 Variations in the ionosphere from solar particle injections may lead to changes in the rates of discharges between thunderstorm and the upper atmosphere – sprites – changing the dynamics and intensity of such storms.

An interdisciplinary science program is needed to discover what influence, if any, solar variability has on Earth's climate and weather systems. To accomplish this, space science and the exploration programs will need to combine the following:

- Study the variations in the solar radiation output and activity cycle with a view to understand the nature of the solar dynamo, building an accurate historical record of solar activity and with the eventual goal of long-term prediction of solar activity.
- Study the climate variability on Earth with particular attention to correlations with changes in the Sun and establishing the phasing and amplitude correlations to solar activity and their relative significance.
- Characterize the different suggested transport mechanisms in the Earth's atmosphere
 that could create the observed climate effects in the biosphere to test which unique
 aspects of these could be use to make measurements to differentiate between their
 effectiveness and applicability. This could eliminate some of the many suggested
 transport mechanisms or suggest new alternatives.
- Use existing models of the neutral, partially and completely ionized atmosphere to build an integrated, dynamic, and realistic model of the impacts of charged particles and energy absorption on a global scale and their propagation in the atmosphere.
- Extend these models to other planets to test their validity against different composition, density and temperature profiles under changing solar bombardment.

Such a program would have application to both the NASA Space Science and Space Exploration programs. It would combine several scientific disciplines that have traditionally been studied separately to benefit both science and society:

- Space Science: Solar Physics, Planetary and Earth Sciences: Contributing to the resolution of the often contentious debate on the origin of global warming and how well we will be able to predict its course and impact on society. Making an initial step in comparative planetology by comparing the effect of the solar bombardment of different planetary boundary conditions presented by the Moon, Mars, and Venus.
- Space Exploration: An improved understanding of the modes of the solar dynamo and drivers of long-term solar variability, addressing the likely extremes in the radiation environments explorers could experience on extended missions to the Moon and Mars. There would also be relevance to understanding the potential for viable life on planets discovered in other solar systems with suns that are either more or less magnetically active than the Sun.